Calibration and Validation of the SRTM C-Band Mapping System

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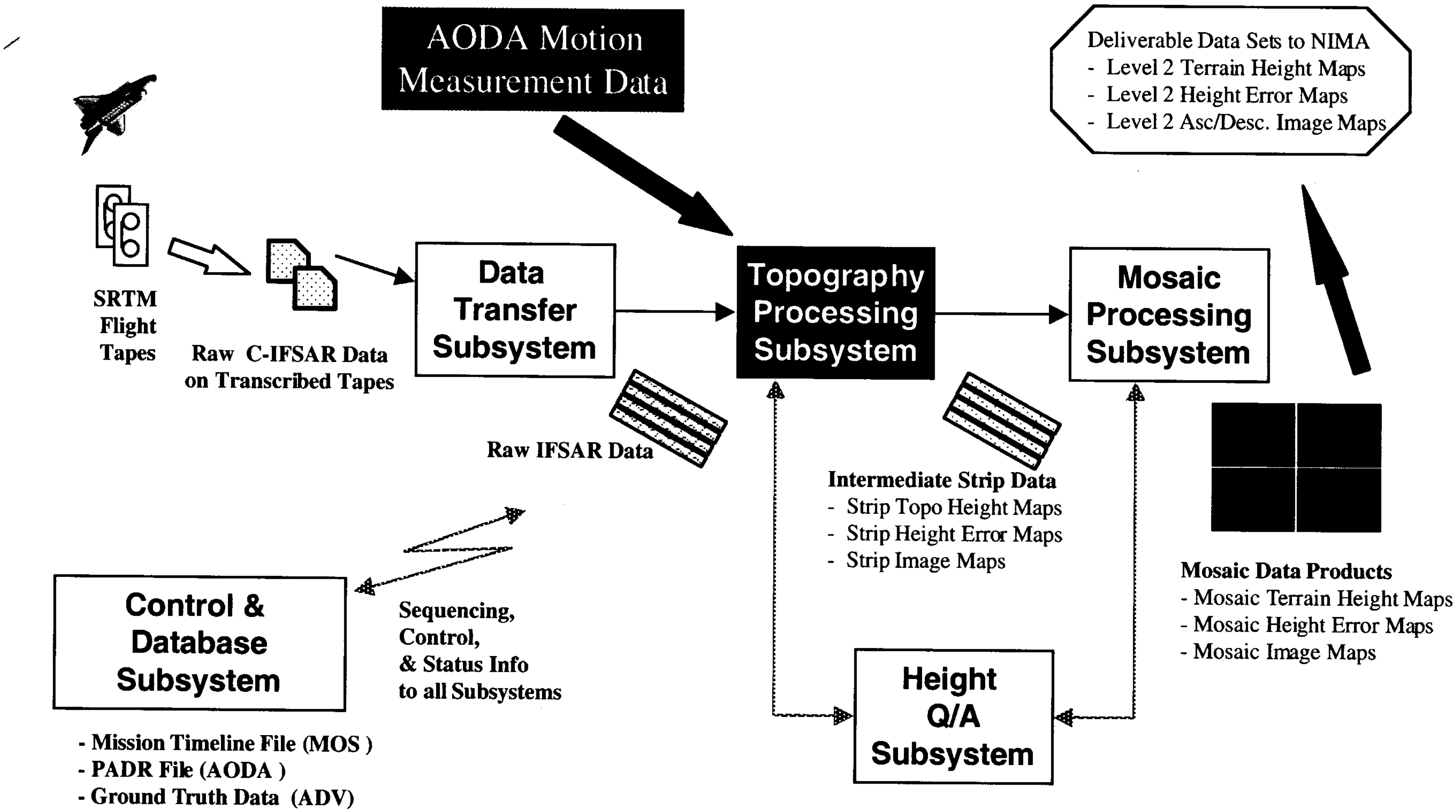
Overview

- SRTM Ground Processing System
- Processing
- Mosaicking
- Ground Truth
- Accuracy Results
- Conclusions

SRTM Ground Data Processing System

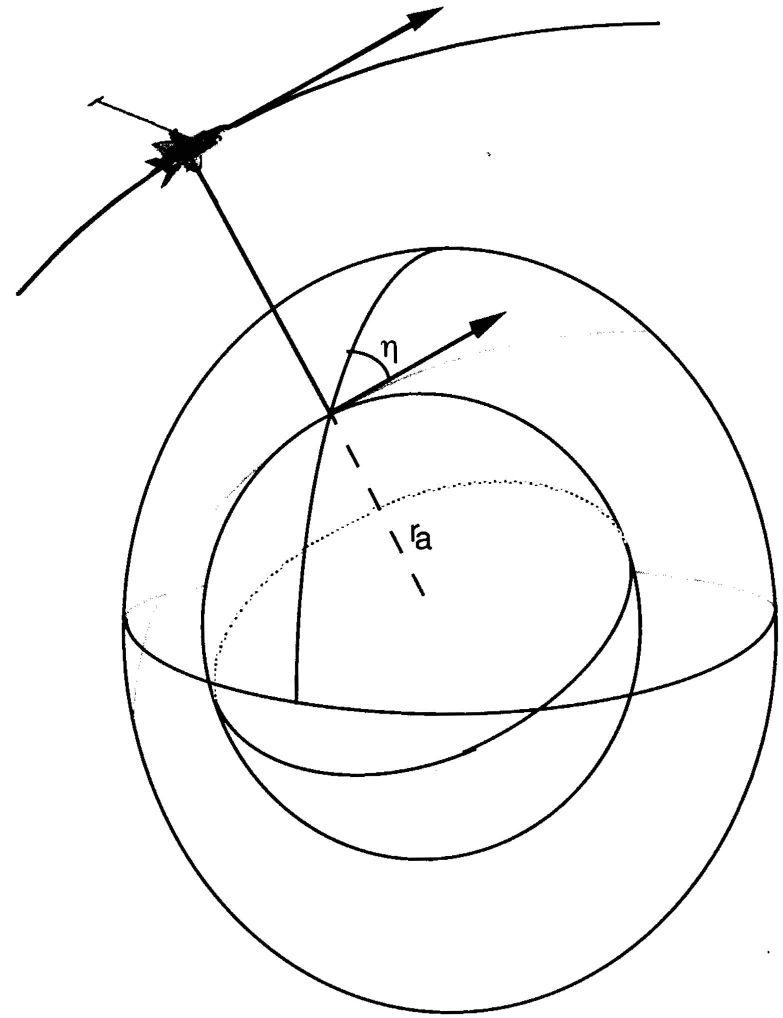


The SCH Coordinate System

- The processor uses a coordinate system (sch) which is a spherical coordinate system that best approximates the ellipsoid in the along track direction.

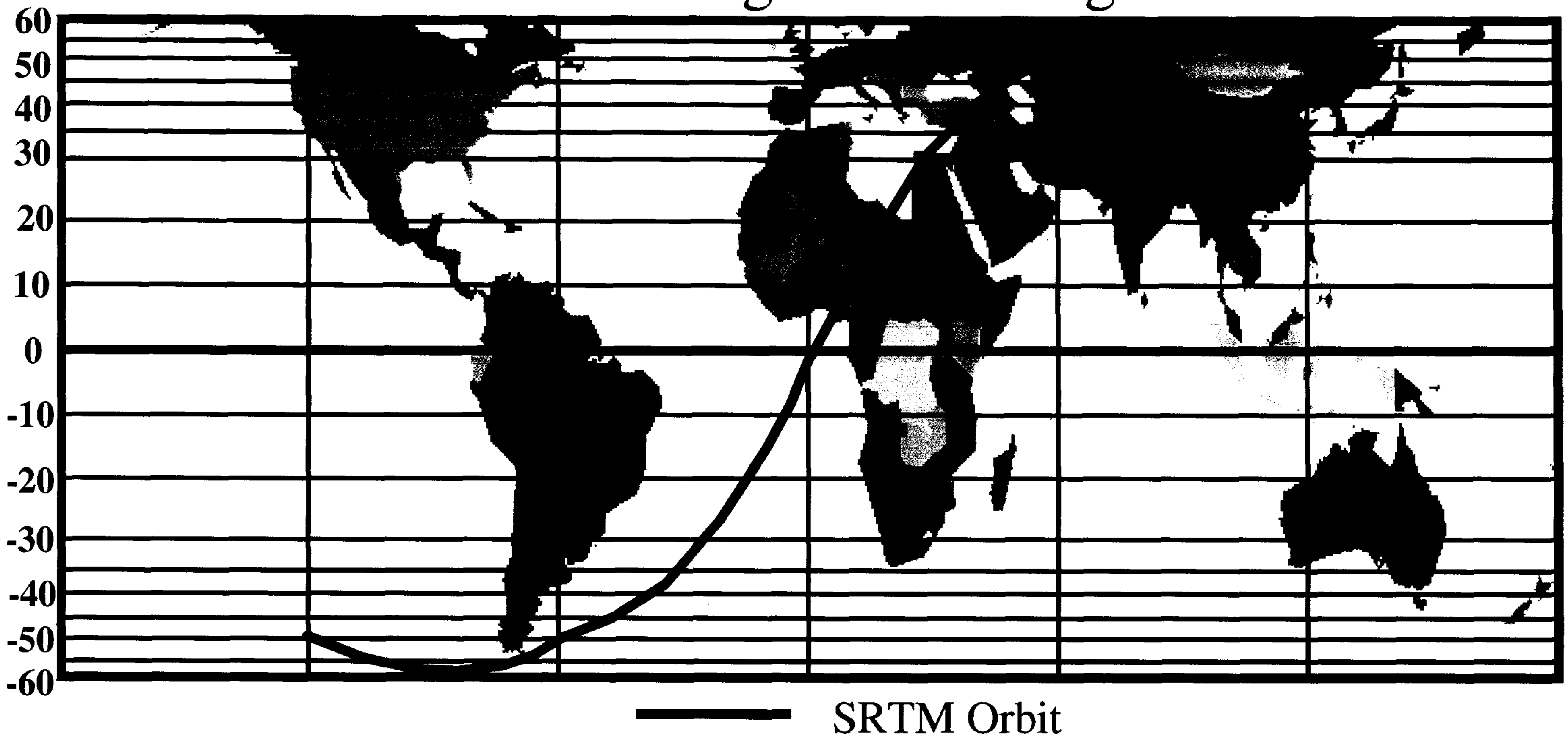
- This coordinate system is readily referenced to WGS-84 coordinates, provides a convenient and accurate means of parametrizing the flight path by distance, and provides a well defined coordinate frame for determining target position vectors from the phase data.

$$r_a = \frac{r_e(\lambda) r_n(\lambda)}{r_e(\lambda)\cos^2(\eta) + r_n(\lambda)\sin^2(\eta)}$$



- η is sensor heading at peg point

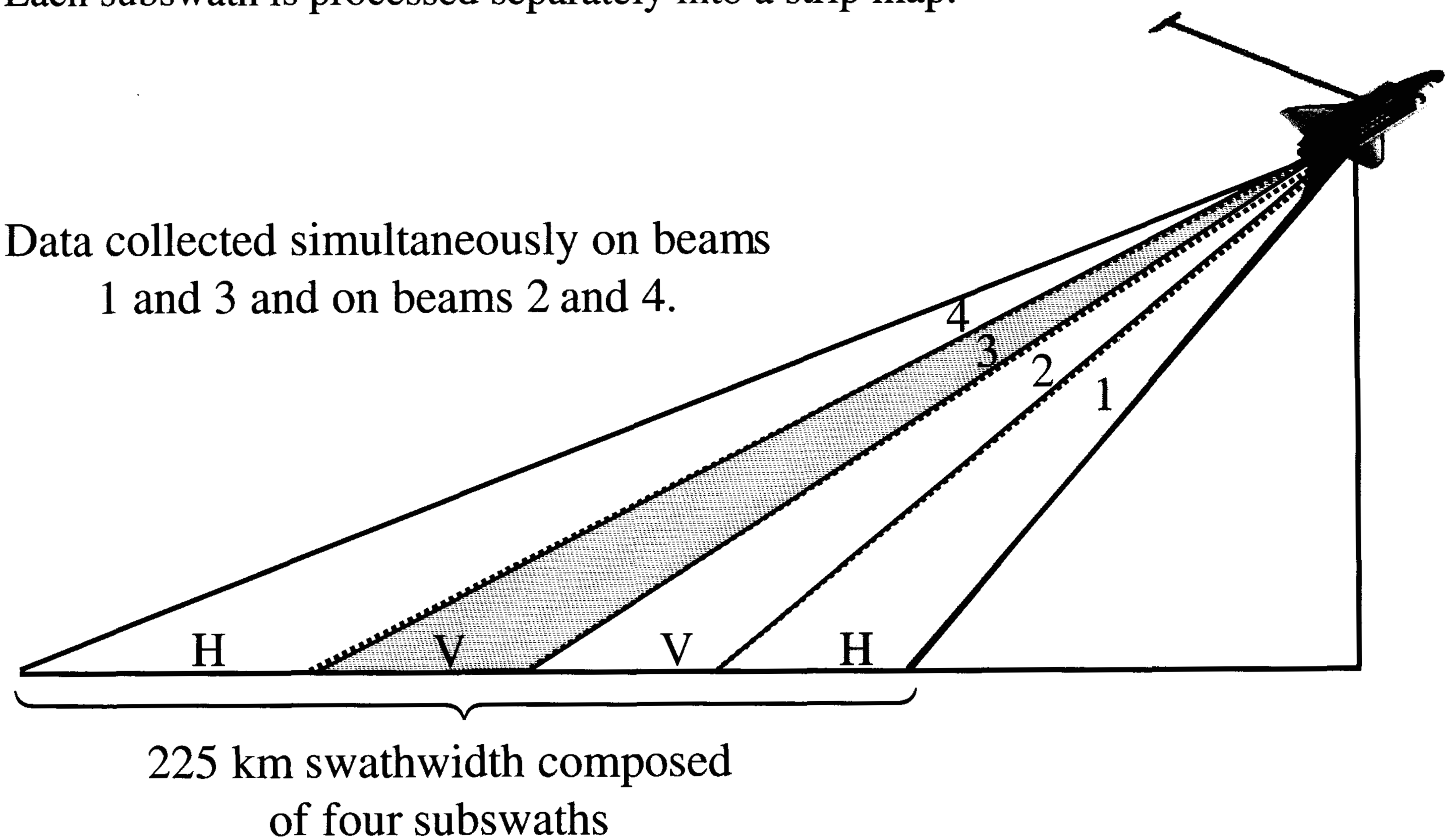
SCH Constant Peg Latitude Regions



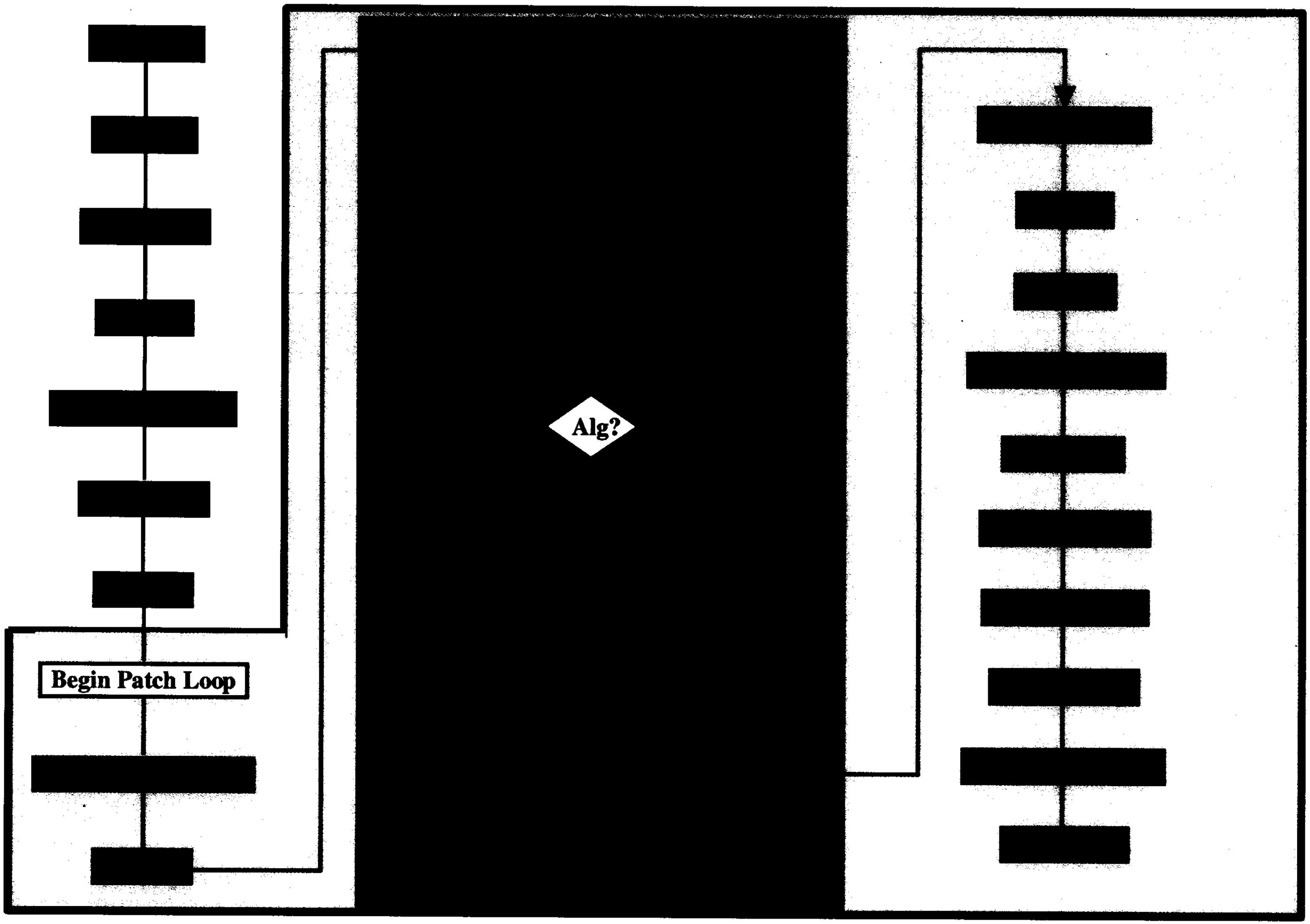
- Mapped region is divided into 5° and 10° latitude bands (≈1500 km of along track distance) where the SCH peg latitude is fixed to a value at the center of the band. Maximal projection height differences from ellipsoidal heights is approximately 40 m.
- Maximal file size for a given subswath is approximately 1.6 Gbytes. This size file can be addressed with either 32 or 64 bit file addressing operating systems.

Data Collection Basics

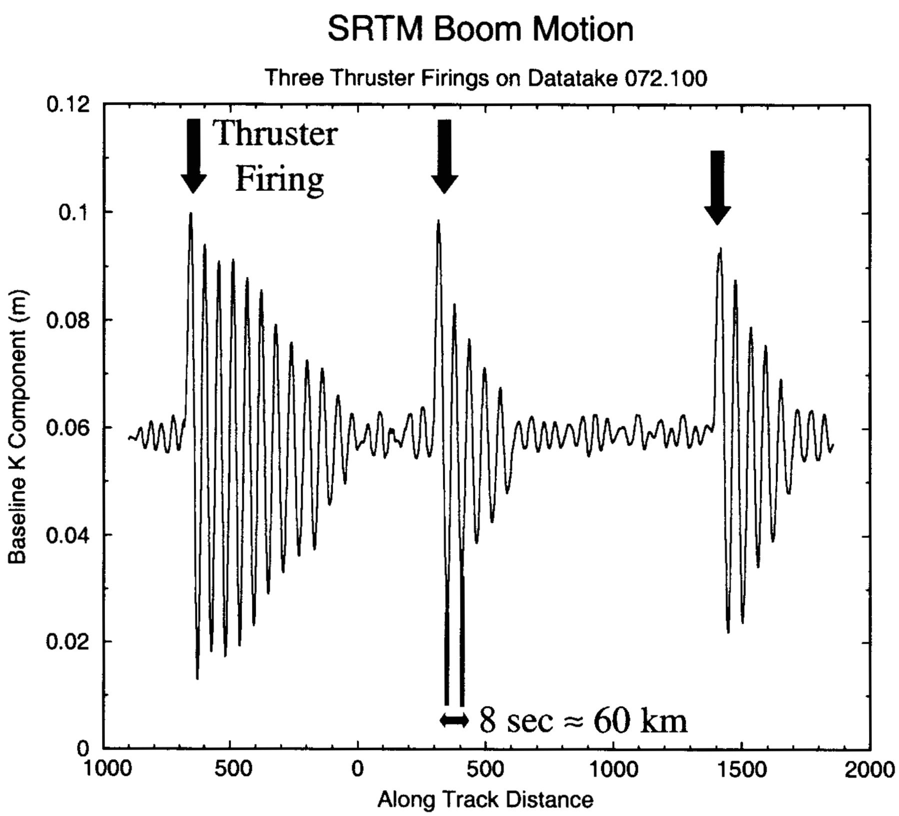
- SRTM collected data in a SCANSAR mode whereby it alternately switched between two beam positions in the cross track direction to increase the swathwidth at the expense of along track resolution. Since SRTM is a polarimetric radar it applied this same procedure to both vertical (V) and horizontal (H) polarizations to achieve an effective swathwidth of 225 km. Each subswath is processed separately into a strip map.



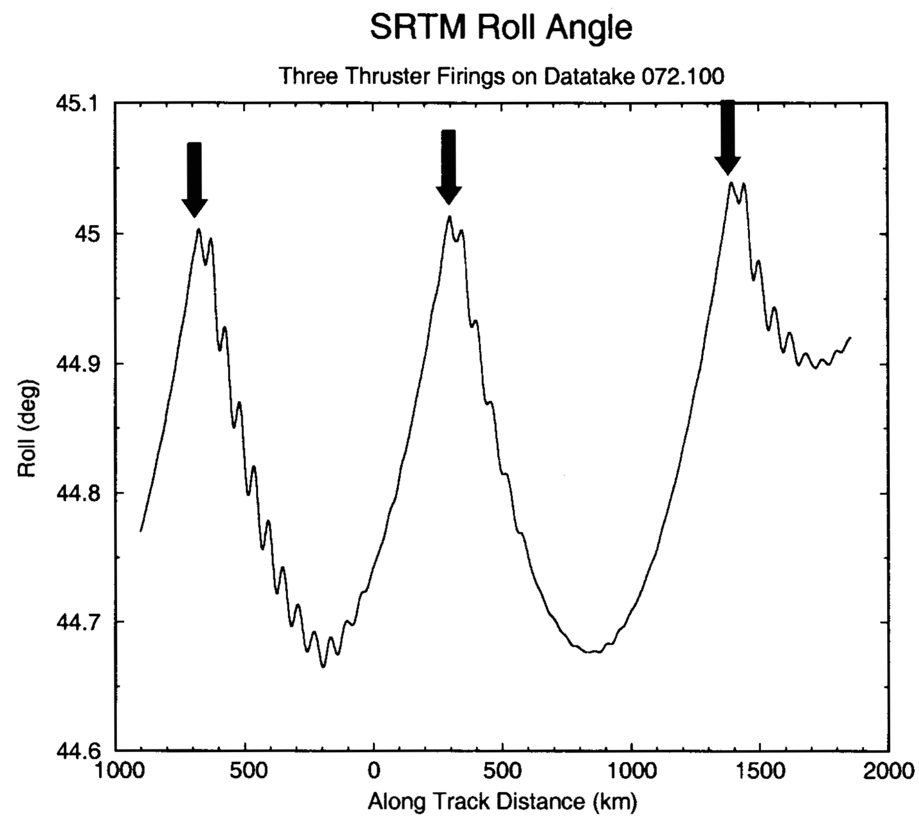
Topographic Processing System



AODA Data and Need for Motion Compensation



Plot of Baseline K Component



Plot of Roll Angle

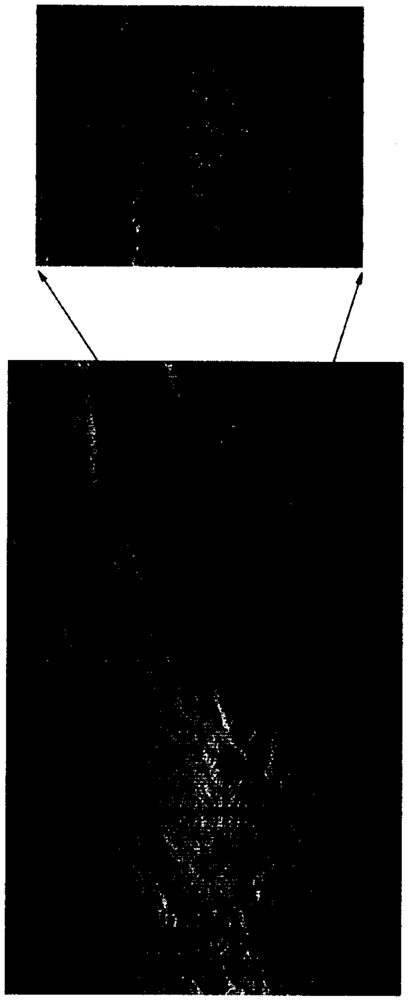
- Motion compensation is required to account for boom dynamics as well as shuttle attitude changes. Left uncompensated these motions would generate hundreds of meters of height error.

Burst Processing Algorithms

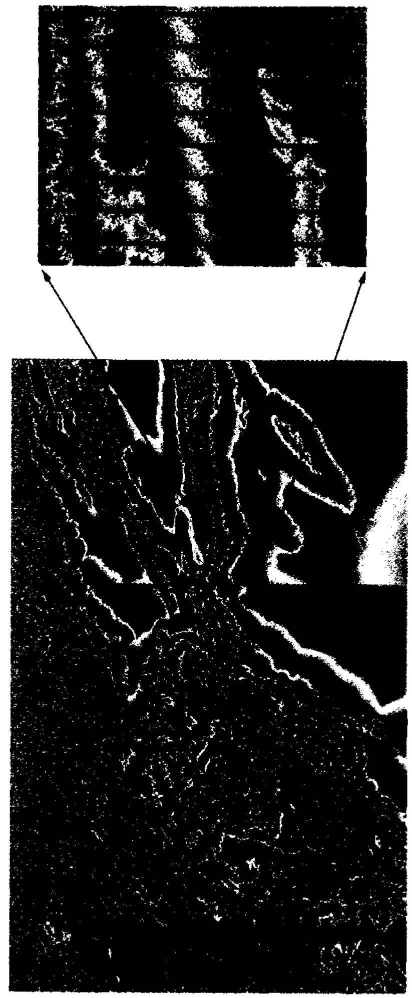
- Problem:
  - Choose algorithm to perform azimuth compression over the synthetic aperture, taking into account the burst discontinuities in the observing strategy
    - performance accuracy
    - efficiency
    - simplicity and ease of implementation
- Options:
  - Strip-Mode Processing - Standard Doppler processing as though there were no burst strategy employed
  - SPECAN Processing (M. Jin) - Deramp FFT method employed in RADARSAT ScanSAR processor
  - Burst Isolated Doppler Processing
  - Modified SPECAN Processing

TPS SRTM Patch Processing Example

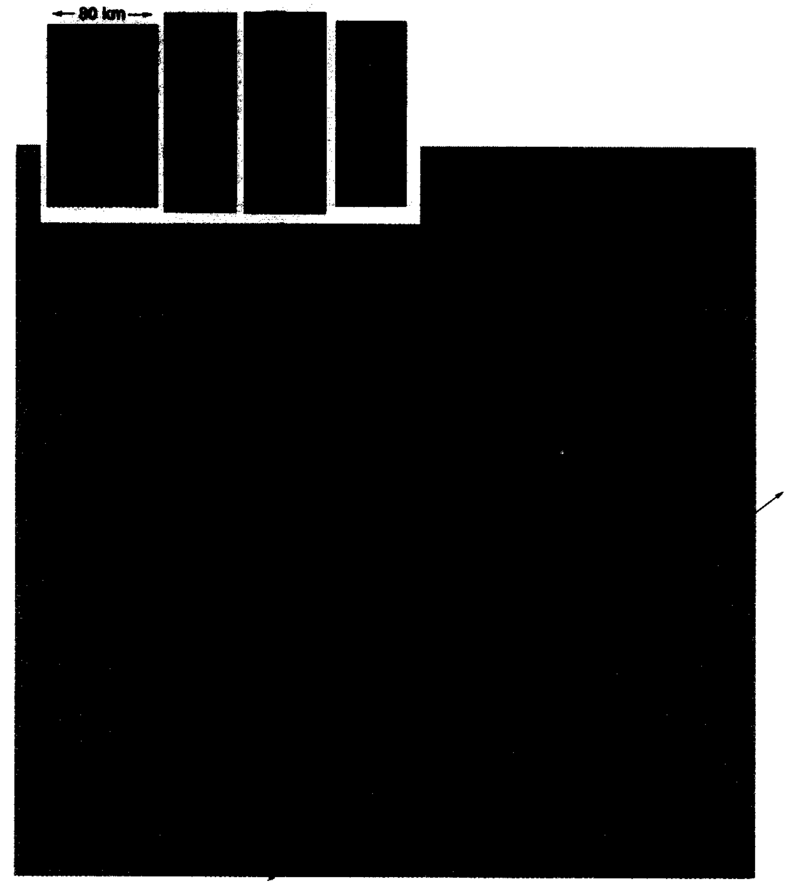
Burst Interferogram Brightness Images



Burst Interferogram Phase Images

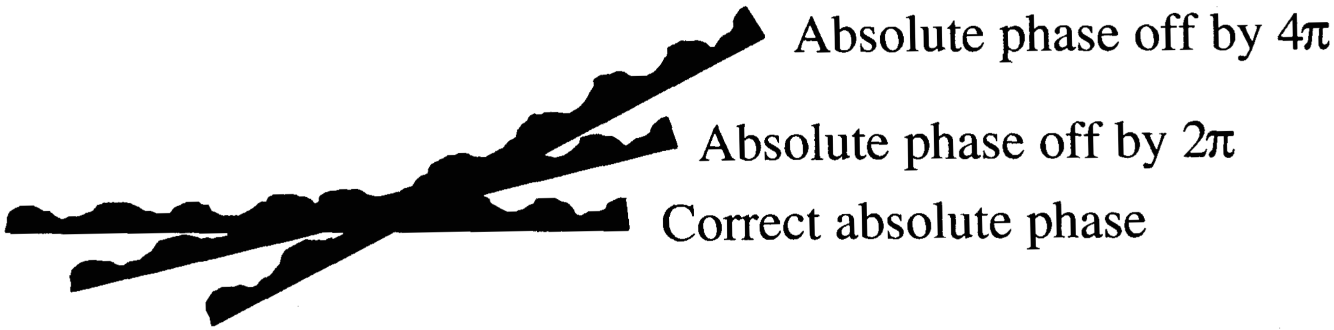


Uncalibrated Strips



Absolute Phase Determination

- Over the ocean at the beginning of every datatake will use the known height of the ocean to determine the absolute phase. Ocean height accuracy for absolute phase determination only needs to be about half an ambiguity height (amount of height change for one cycle of phase) which is about 60 m.



- Over land absolute phase determination will use a low resolution DEM (500 m posting) to resolve the absolute phase where such data exists. The low resolution DEM database will be updated with processed SRTM data to fill gaps in the existing database. Database updating will occur after each strip is processed.

Regridding Options

- The problem of interpolating data that is not sampled on a uniform grid, that is noisy, and contains gaps is a difficult problem.
- Several interpolation algorithms have been implemented
  - Nearest neighbor - Fast and easy but shows some artifacts in shaded relief images.
  - Simplical interpolator - uses plane going through three points containing point where interpolation is required. Reasonably fast and accurate.
  - Convolutional - uses a windowed Gaussian approximating the optimal prolate spheroidal weighting function for a specified bandwidth.
  - First or second order surface fitting - Uses the height data centered in a box about a given point and does a weighted least squares surface fit.

Adaptive Regridding Parameter Determination

- In the adaptive regridding process it is desired to adjust the amount of smoothing depending on the amount of topography compared to the intrinsic measurement noise.
- The amount of noise reduction and smoothing depends on the size of box used for the regrid point estimate and the amount of weighting employed.
- For computational efficiency is desired to have the weighting depend only on the measurement noise and not vary spatially with the data, however this reduces the flexibility in controlling the amount of smoothing vs noise reduction.
- The box size for fitting is determined by comparing the χ^2 residual of the surface fit to the mean of the estimated height noise as determined from the correlation in the box.
  - large residuals compared to the intrinsic noise level means that surface fit is not a good model for the local topography and therefore a smaller box size should be use.
  - each box size must be checked to insure that the points within the box the correct geometric distribution as needed by the algorithm employed.

Radiometric Compensation

- Radiometric correction is done in four steps
  - Compensation for range squared amplitude reduction is applied after range compression.
  - Azimuth antenna pattern correction is applied for each burst after azimuth compression.
  - Elevation antenna pattern correction is applied after height reconstruction.
  - Correction for the area projection factor is applied during regridding (an option for area reprojection with a constant incidence and illumination angle is also available)

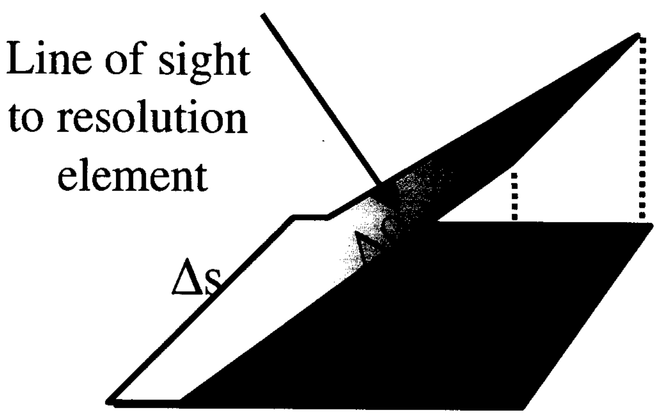
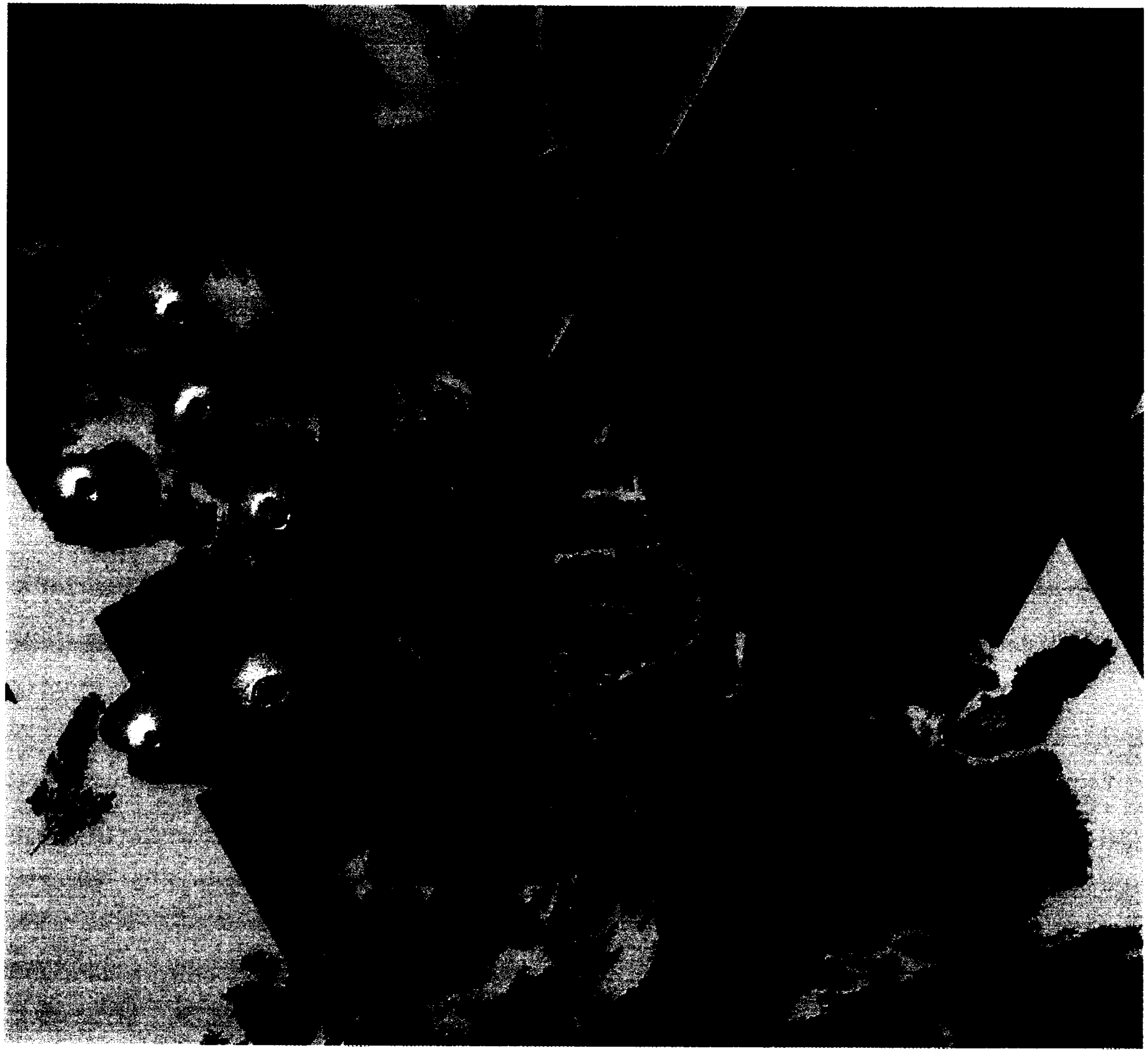


Image brightness corrected by the amount of ground area seen by the radar for each resolution element.

$$A = \frac{\Delta\rho\Delta s}{\langle \hat{n}_{\Sigma}, \hat{n}_I \rangle} = \frac{\Delta\rho\Delta s\sqrt{1-\sin^2(\gamma_c)\sin^2(\gamma_s)}}{\sin(\theta-\gamma_c)\cos(\gamma_s)}$$

A is the area the on the ground responsible for the scattering where $\Delta\rho$ and Δs are the range and along track resolution element dimensions. and γ_c and γ_s are the cross track and along surface tilts respectively.

Galapagos Data



Radiometrically Corrected SRTM Image

Range radiometric correction applied

Range radiometric and azimuth antenna pattern correction applied

Range radiometric and azimuth and elevation antenna pattern correction applied

Beam 1 data collected over California on Day 4 of mission.

Ground Truth Data Used for System Validation and Accuracy Assessment

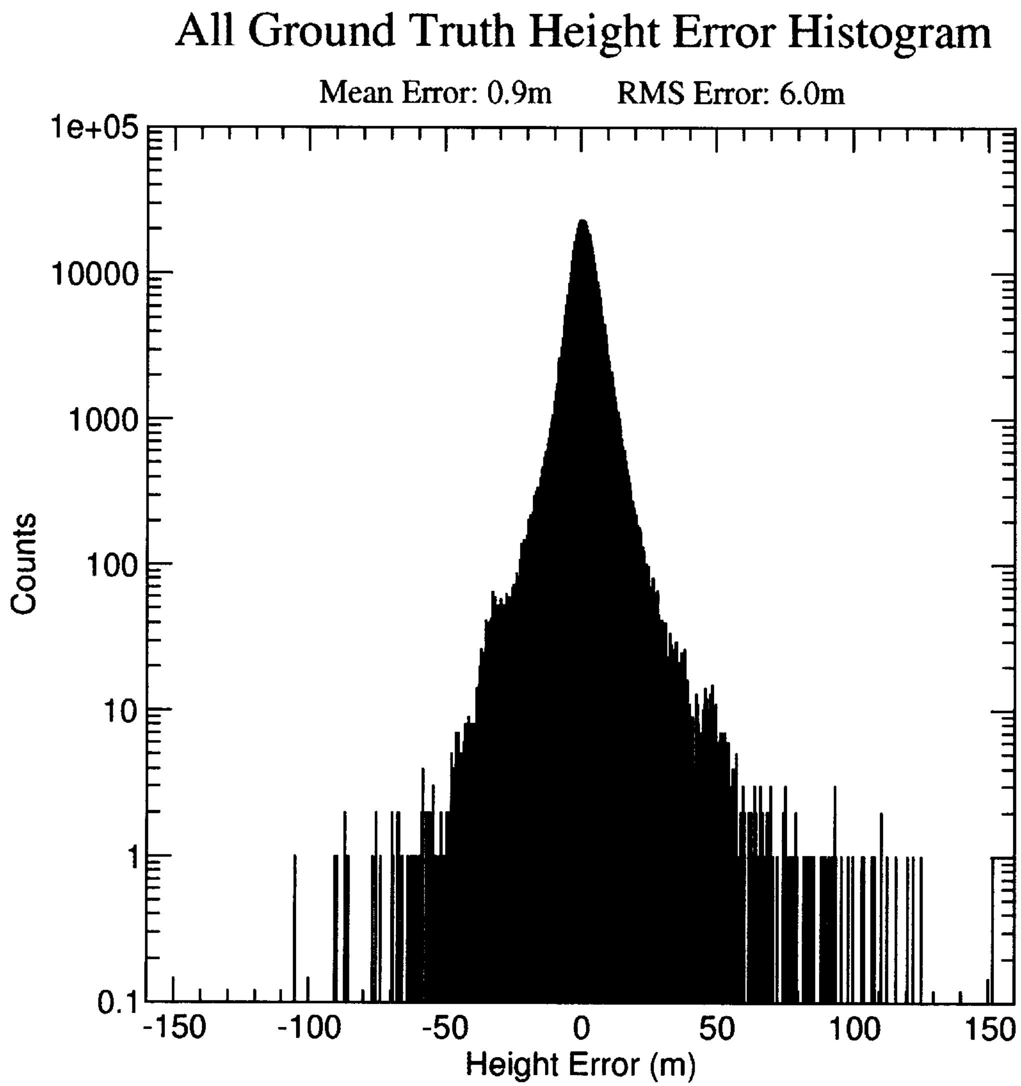
- Kinematic GPS tracks
- Corner Reflectors
  - United States and Australia
- Other NIMA and JPL derived GCP's
- DEM "Chip" data generated by NIMA from optical imagery
- Altimeter derived GCP's (JPL)

Known SRTM Error Sources

- Random error: decorrelates within a few pixels, depending on surface smoothness
- Residual Processing Errors: Random error with wavelengths on the order of 1-10's of kilometers. Estimated RMS: 1m
- Residual 7 second ripple errors (50km wavelength), RMS ~1m
  - Much reduced in the final production data since the source of this error was located and mostly removed from the motion data
    - Source of ripple was an instrument anomaly in the star tracker
- Residual PADR errors (dominant periods > 100 seconds, or 700 km)
- Residual mosiacking errors
- Other "unknown" errors

Summary Height Error Histogram

- Data used: all GCP's, NIMA Chips, Kinematic GPS



Height Performance Summary

- Based on about 0.5 million ground control points, SRTM has a absolute height accuracy of 8.8 m, at the 90% confidence level.
- Some isolated large outliers (errors > 30m) are observed
  - Some outliers are suspected KGPS errors
  - Some outliers are present in GCP's which are close to other GCP's with small errors. What are the GCP error bars?
  - Other outliers may be related to residual SRTM unwrapping errors
  - SRTM exceeds the absolute height accuracy requirement by almost a factor of 2

Horizontal Shift Conclusions

- SRTM heights have planimetric errors less than 1/3 a of pixel (10 m) in both directions.

- The shifts between SRTM and the NIMA patches are probably random. 71 vector determinations give an average shift of 1.4 m towards 42° (~ northeast)

Given that the shift results are significantly different using the different ground truth datasets, it seems unlikely that the observed shift with respect to the DTED-2 data represents a miss-registration (geolocation) of the SRTM data.

Calibration Lessons Learned

- Due to the novel nature of the SRTM instrument several lessons on calibrating space based interferometric mapping systems were learned.
  - Electronic scanned antennas change the phase center and complex phase as they are steered. This means that active steering of the beams during data collection presents a serious calibration challenge for future systems.
    - May want to limit steering angles to a fixed set where calibration data is available for future systems.
    - This would preclude a system of beam tracking such as the BAT used on SRTM.
  - Using the ocean for calibration worked extremely well for SRTM.
    - However, for systems that aspire for submeter accuracy they will have a more difficult using water for calibration due to local variations when data was collected.
  - ScanSAR system provide extra swath but the burst-to-burst noise in very sensitive to the Doppler and therefore to the yaw, pitch and azimuth steering angle calibrations.

SRTM Summary

- Have processed over 2/3of cells in the world over multiple continents and analysis of data shows that
  - Vertical accuracy is better than 2 times the requirement
  - Horizontal accuracy meets or exceeds requirements
- Global production began on April 10, 2002 with the the processing of North America.
  - Data is delivered on a continent by continent basis with each continent taking approximately 6 weeks to 2 months to complete.
  - Strip map processing is complete expect for some minor reprocessing work.
  - North America, South America, Australia are complete.
  - Mosaicking of Eurasia and Africa are in progress.
- Planned completion of all data processing at end of calendar year.

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